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Effects of surface application of gypsum in corn intercropped with jack bean (*Canavalia eusiformis*) with different soil penetration resistance

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Abstract

This study aimed to evaluate production components, yield of maize intercropped with jack bean and soil resistance to penetration using different doses of gypsum. The experimental design was a randomized complete block design in split plots with four replications and was carried out during season 2013/2014. The main plots were maize intercropped with jack beans and maize sown alone, and the subplots were six doses of gypsum (0, 1, 2, 3, 4, 5 t ha-¹). Thirty days before maize sowing gypsum doses were manually applied to soil surface. The spacing between rows was 0.70 m, 4.2 sowing seeds per meter. Jack bean was manually sown two days after maize was sown in inter-row spacing. Production components and maize yield were assessed. After maize harvest, soil resistance to penetration was assessed. Gypsum doses promoted linear increases in the stem diameter of maize. Maize intercropping with jack bean (*Canavalia eusiformis*) did not affect the maize components of production and productivity, but reduced the soil penetration resistance. Rates of agricultural gypsum did not influence the productivity; however, it promoted a reduction in SPR at dose of 2.0 t ha^{-1}.

Keywords: Calcium sulphate; compression; conservationist systems.
Abbreviation: SRP_Soil resistance to penetration.

Introduction

Intensive cultivation of soybean and maize under no-till system and crop rotation, with high straw production, has been used in the western region of Paraná for over 35 years.
According to Lovato et al. (2004), an estimated 8 t ha^{-1} year/ dry mass is needed to maintain this cultivation system in the southern region. However, over the years the crops used in rotation (wheat, oats) were reduced; soybean or maize is grown in the summer and maize crop in the winter. Consequently, dry matter intake is insufficient to maintain the farming system, causing soil compaction. The use of intercropping can be an excellent alternative way to maintain this cultivation system, as it increases dry matter accumulated in the soil (Chioderoli et al. 2012; Seidel et al. 2015), promotes the improvement of physical and chemical properties of the soil and increases water infiltration rate (Conceição et al., 2005).

Maize is considered a promising food crop for use in intercropping, although few studies were conducted on jack bean (*Canavalia ensiformis*) cropped as green manure. According to Perin et al. (2007), jack bean is very suitable for intercropping due to its physiological characteristics, prostrate growth habit (harvested at ground level) and adaptation to diffuse light conditions, generating increased dry matter of maize (Henrichs et al., 2002). The use of agricultural gypsum can also favor the improvement of physical and chemical properties of soil. Gypsum is a byproduct of phosphoric acid that mainly consists of calcium phosphate and low concentrations of P and F (Vitti, 2000).
The efficiency of gypsum in the improvement of chemical properties of soil has been demonstrated in many studies. These improvements result from the increase in the concentration of calcium (Caires et al. 2003; Serafin, 2012;), and sulfur (Neis et al. 2010), the formation of less toxic species of Al ($AlSO_4^+$) (Caires et al., 2006; Soratto and Crusciol, 2008; Raij, 2008) and Al^{3+} precipitation (Zandoná et al., 2015), leading to better root development and increased water and nutrient uptake by plants (Serafim et al. 2012). This can be explained by the fact that calcium is the main component of root cell wall, which acts on cell elongation and proliferation (Silva et al., 2013). Gypsum can increase water infiltration rate and reduce surface runoff by reducing surface waterproofing and the formation of crust (Favaretto et al. 2006, Silveira et al. 2008). These effects would contribute to increase water retention capacity in soil, resulting in increased production. However, Serafim et al. (2012) did not observe increase in water infiltration rate in the soil following the application of different doses of gypsum.

According to Silva, et al. (2013) the use of agricultural gypsum can favor the resilience of soil organic matter. Decomposed crop residues release low-molecular-weight organic acids capable of forming organic complexes with calcium and clay (Amaral et al., 2004), increasing stabilization and the residence time of organic matter in the soil (Bronick and Lal, 2005). Soil resistance to penetration (SRP) is a parameter that can be used to assess whether soil physical properties favor root growth. SRP has a good correlation with root growth, is more sensitive than soil density and porosity, providing an accurate assessment of soil compaction (Abreu et al., 2004).

Therefore, the present study aimed to assess production components, the yield of maize intercropped with jack bean,

Table 1. Effect of different management systems on ear insertion height (cm), maize stem diameter (cm), ear diameter (cm), ear length (cm), mass of 1000 grains (g) and productivity (kg ha^{-1}).

Maize Managerment Systen	Ear insertion height (cm)	Maize stem diameter (cm)	Ear diameter (cm)	Ear length (cm)	Mass of 1000 grains (g)	Productivity Kg ha^{-1}
Intercropped with jack bean	82.03 a	2.89^{ns}	5.07	18.13^{ns}	286.34 ^{ns}	8238^{ns}
No Intercropped	78.33 b	2.82	5.04	17.94	284.48	7864
DMS	0.469	0.274	0.104	1.889	1.025	7156

Means followed by the same lowercase letters in the column do not differ by Tukey's test at 5% probability

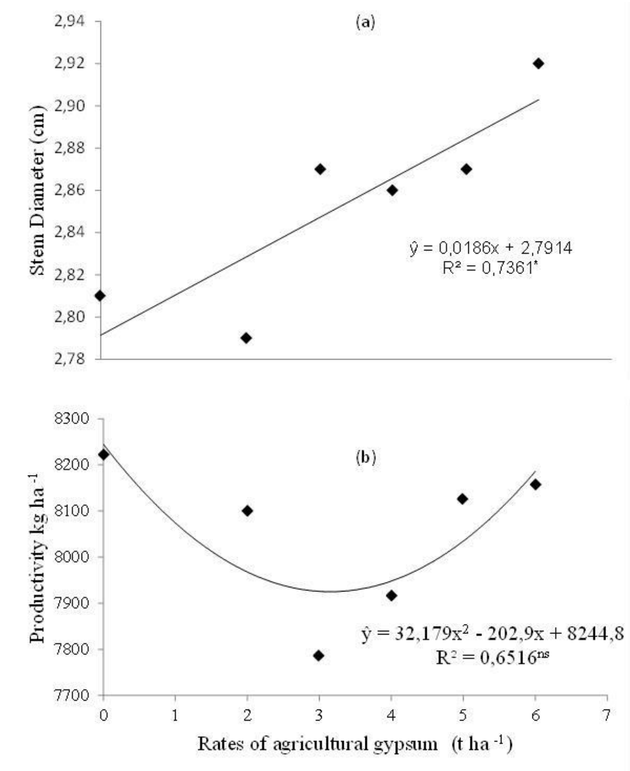

Fig 1. Maize stem diameter (a), and productivity (b) in function of surface application of agricultural gypsum in an Oxisol, during the summer crop seasons of 2013 and 2014.

as well as soil resistance to penetration using different doses of agricultural gypsum.

Results and Discussion

Production components and productivity

The results demonstrated an isolated effect of gypsum doses on stem diameter: increase in gypsum doses generated linear increase in stem diameter (Figure 1 a). In addition to sustaining the leaves and flower parts, the maize stem also provides a reserve (accumulation of photo-assimilates) for grain filling in case of stress (Cruz et al., 1996). However, in this experiment the diameter did not correlate with yield. The treatments had no effect on spike insertion height, spike length, mass per 1000 seeds and yield ($p \leq 0.05$). It was presumed that the use of agricultural gypsum increased crop yield, as it is a source of calcium, magnesium and sulfur and corrects the effects of subsurface aluminum toxicity; however, this was not observed in the present study, probably due to the existence of appropriate levels of these elements, as shown in chemical analysis. Such fact can be corroborated by the result of the analysis of yield of the treatment without agricultural gypsum: 8222 kg ha^{-1} (Figure 1 b).

In contrast with our findings, Zandoná et al. (2015), Maschietto (2009) reported increase in the production of maize grains with the use of gypsum, due to the increase of Ca and S in leaf tissue. In a study on the combination of lime and gypsum in no-till system, Caires et al. (2003) reported an increase of 17% in the production of maize grains.

Maize crop management influenced spike insertion height. The maximum spike insertion height was observed in intercropping with jack bean (82 cm), while in maize without intercropping the height was 78.33 (cm). Maize and jack bean intercropping did not reduce maize yield, which is very promising, since this green manure can provide several physical, chemical and biological benefits to the subsequent crop (Table 1).

Perin et al. (2007) and Fontanetti (2006) also found that intercropping maize and jack bean, when simultaneously sown, did not affect maize and maize grain production, is a viable system, which also improves soil properties.

Regarding the results for interaction between intercropping and gypsum doses, there were statistically significant differences for stem diameter. In maize intercropped with jack bean stem diameter was adjusted with the application of a quadratic equation, and in maize sown alone there was no adjustment with any type of equation. The largest stem diameter was obtained with the dose of 4.83 t ha^{-1} of agricultural gypsum (Figure 2).

Soil resistance to penetration

Analysis of soil resistance to penetration (SRP), after the application of gypsum doses, showed adjustment to quadratic equation. The highest SRP (3.5 MPa) was obtained at the dose of 1.76 t ha^{-1} of agricultural gypsum (Figure 3). SRP values higher than 2.0 Mpa are considered critical for most crops, as they may restrict water infiltration and impair root growth, with impact on crop yield (Klein and Camara, 2007). The increase in gypsum doses above 1.76 t ha $^{-1}$ reduced SRP, demonstrating that gypsum can improve physical properties of the soil, by increasing the attraction of soil particles and favoring soil aggregation.

According to Zhang and Norton (2002), gypsum can effectively improve soil structure through a cation bridge binding clay minerals and soil organic carbon. Improvement in soil aggregation is important, particularly during drought periods because crops with more developed root systems will be less affected by the water deficit stress, as they will be able to absorb water from deeper soil layers, maintaining higher photosynthetic rates, and consequently increasing yield.

Figure 4 shows the average results for SRP at a moisture rate of 0.15 m^3 m^{-3}. Soil management was found to influence SRP at all soil depths, and the lowest values were observed for maize intercropped with jack bean. The highest SRP value was observed in crops of maize sown alone at the depth of 0.25 m (5.13 Mpa). RSP values above 2 MPa have been associated to restriction to plant root growth, although this critical value depends on the species of the plant grown. The results demonstrated that before cultivation the soil was compacted, and that jack bean roots improved the physical properties of the soil. Figure 5 shows the results of the interaction between management system and gypsum doses. In maize with and without intercropping, the data on SRP showed quadratic adjustment for gypsum doses, and the highest SRP values were observed in maize sown alone (values above 2.0 Mpa, which however did not impact yield) In the area sown with maize intercropped with jack bean, the application of agricultural gypsum at doses above 3 t ha^{-1} reduced SRP values, and in the area sown with maize alone, this reduction was observed after application of gypsum doses above 2 t ha^{-1}.

Corroborating these findings, Bonini and Alves (2012), in their study of different managements of Red Latosol, found that the treatment with pigeon pea and jack bean increased the physical properties of the soil and promoted conditions similar to those of Cerrado soil.

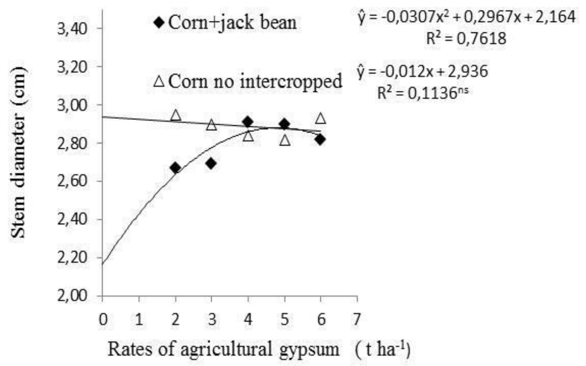

Fig 2. Effect of surface application of rates of agricultural gypsum in an Oxisol and management system in maize stem diameter.

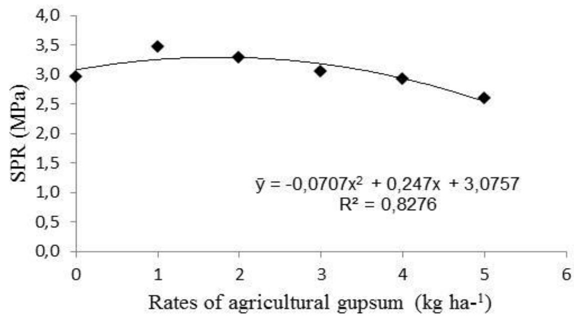

Fig 3. Effect of different rates of agricultural gypsum in the soil penetration resistance in an Oxisol after the maize harvest.

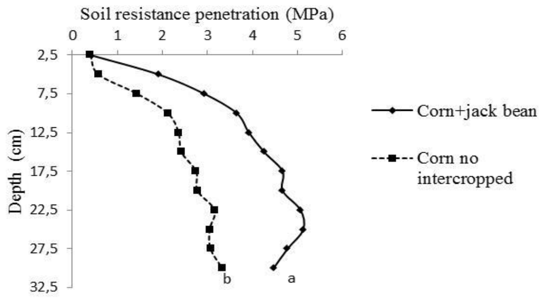

Fig 4. Soil penetration resistance in an Oxisol at different depths after the maize harvest intercropping with jack bean e no intercropping.

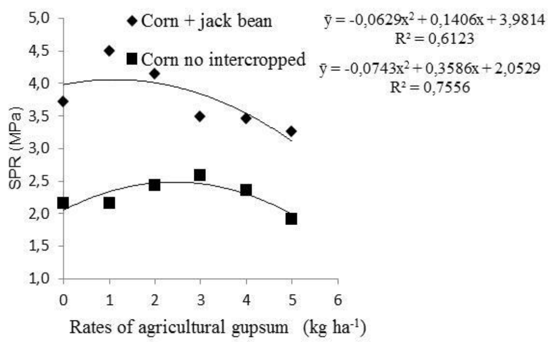

Fig 5. Soil penetration resistance in an Oxisol with different management system and rates of agricultural gypsum.

Contrasting results were obtained by Muller et al. (2012) in their assessment of gypsum doses applied to Red Latosol under no-till system. The authors reported increase in SRP following the use of agricultural gypsum, though below the critical limit. In turn, Cunha et al. (2009) did not report statistically significant differences in SRP after five years of cultivations under different management systems and the application of gypsum and limestone.

Materials and methods

Site and climate

The experiment was conducted at *Núcleo de Estações Experimentais* of UNIOESTE, Campus de Marechal Cândido Rondon. The average altitude at the experiment site is 420 m and the geographical coordinates are 24º 31' south latitude and 54º 01' western longitude. The soil in the region was characterized as clayey Oxisol (Santos et al., 2013). The climate was subtropical Cfa, with rainfall well distributed throughout the year and hot summers, according to Koppen classification.

Experimental design and treatments

The experimental design was a randomized complete block design in split plots with four replications. The main plots were maize intercropped with jack bean and maize sown alone, and the subplots were six doses of agricultural gypsum (0, 1, 2, 3, 4, 5 t ha^{-1}). Each subplot had a total area of 31.5 m^2 (4.5 m wide and 7 m long).

Chemical characterization

Before the experiment, samples were collected at soil depth 0.0 – 0.20 m for determination of chemical and particle size properties. Chemical analyzes were performed according to the methodology proposed by Raij et al. (2001). The results obtained were as follows: pH ($CaCl_2$)= 6.05; O. M.=24.61 g dm^{-3}; P= 2.36 mg dm^{-3}; Ca^{2+}= 6.61 $cmol_c\ dm^{-3}$; Mg^{2+}= 1.77 $cmol_c\ dm^{-3}$; K^+= 0.25 $cmol_c\ dm^{-3}$, Al^{3+}= 0.00 $cmol_c\ dm^{-3}$, $H^+ + Al^{3+}$= 2.54 $cmol_c\ dm^{-3}$ e V = 77.26%.

Management and cropping systems

Agricultural gypsum was applied to soil surface thirty days before maize sowing. Hybrid maize (30F53) was mechanically planted using no-till system. Spacing between rows was 0.70 m; 4.2 seeds were sown per linear meter. The base fertilization used was 300 kg ha^{-1} of 10-20-20 formula (N, P_2O_5 and K_2O), respectively. Two days after maize sowing, jack bean was manually sown in inter-row spacing at the dose of 12 kg ha^{-1}. Twenty-one (21) days after maize sowing topdressing fertilization with nitrogen was manually performed at the dose 120 kg ha^{-1}. Manual weeding was performed twice during the crop cycle during the experiment. Pest control was performed with pesticides, according to the technical recommendations for the crop.

Plant height and stem diameter were measured seventy days later. For this, 10 plants were randomly selected in each plot. Maize harvest was manually performed one hundred and forty days after sowing, with the ears collected from the central rows of each plot (floor area). Then, the ears were shade dried and manually threshed. Spike length and diameter, 1000 grain weight were determined based on the eight samples of randomly selected 100 grains weight, with wet weight corrected for 130 g Kg^{-1}. Yield was determined by grain weighing and later by yield estimates (Kg ha^{-1}).

Soil penetration resistance

Soil mechanical resistance to penetration was randomly assessed in the plots using impact penetrometer (Stolf et al., 1983). The impact weight in free fall reached 0.40 m. The impact results in dm^{-1} were converted into impact on soil dynamic resistance (Mpa) through equation (Stolf, 1991): RP = 5.6 + 6.89 N, where: RP= Resistance to penetration in kgf cm^{-2}; N= penetration in impact results in dm^{-1}. For conversion of RP in kgf cm^{-2} to MPa, the result obtained in equation 1 was multiplied by constant 0.0981. The results obtained were subjected to analysis of variance at 5% probability. Statistically significant difference was observed in qualitative variation; Tukey test at 5% probability was used, and regression analysis for quantitative data. The analyzes were performed with SAEG statistical package (Saeg, 2007).

Conclusions

Maize intercropping with jack bean (*Canavalia eusiformis*) did not affect the maize components of production and productivity, but reduced the soil penetration resistance. Rates of agricultural gypsum did not influence the productivity; however, it promoted a reduction in SPR at dose of 2.0 t ha^{-1}.

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